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Demonstration of the Analog Transmission of GPS Spread Spectrum Signals Over Fiber Optic Links

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ABSTRACT

The measurement of the open ocean sea level will require the utilization of space geodetic techniques, especially the Global Positioning System, GPS. In order to meet the challenge of the sea level measurement, the orbits of the GPS satellites must be known to an on-orbit accuracy of less than 50 cm, about a factor of 20 to 50 times better than routinely available from U. S. Air Force sources. This need for highly accurate, reliable, and routinely available orbits motivated the development of a Fiber Optics GPS Orbit Network (FOGON). The main idea of this system is to remote the GPS antennas at accurately known geodetic locations and transmit the GPS analog satellite signals along a phase stable fiber optic link to the GPS receivers which synchronizes the data acquisition of the network. This paper presents the results of a hardware demonstration carried out by members of the Colorado Center for Astrodynamics Research (CCAR) and the Optoelectronic Computing Systems Center (OCSC) at the University of Colorado (CU) which demonstrates that the analog transmission of GPS spread spectrum signals over a 4 km fiber optic link is possible with minimal degradation to GPS receiver operation.

INTRODUCTION

With the use of the NAVSTAR Global Positioning System (GPS) constellation [1], it is possible to compute accurate receiver positions in both low Earth orbit and on the surface of the Earth. However, this positioning accuracy is directly proportional to the accuracy of the GPS orbits that are used in the estimation process. Limitations on the GPS orbit accuracy and reliability motivated the preliminary study of a unique Fiber Optics GPS Orbit Network (FOGON) which uses fiber optics technology that could provide accurate and reliable GPS orbits for scientific applications such as mean sea level determination. FOGON will consist of relatively closely spaced tracking stations (~40 km) that are connected by fiber optic links, which will synchronize the data acquisition at each site to near Hydrogen maser stability [2]. This time and frequency stability enables the network to operate in a differential mode which is essential to accurately determine the GPS satellite orbits with a regional network. The challenge is to devise a method of exploiting the

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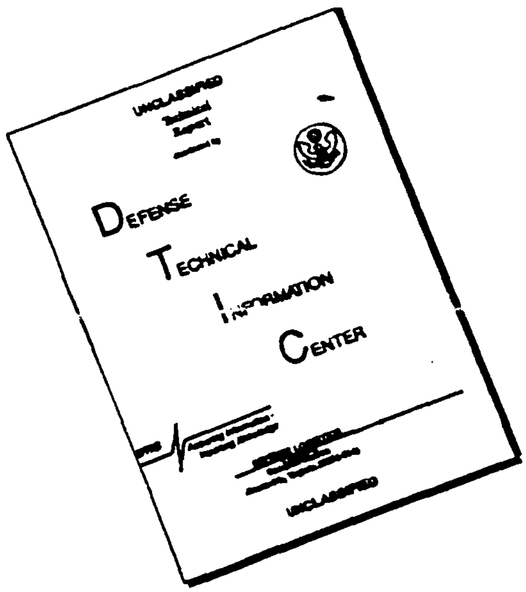

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advantages of highly stable timing and reduced transmission media effects to overcome the reduced sensitivity of relatively short baselines compared to long baselines which are usually exploited for precision orbit determination.

A preliminary covariance study has been performed on the proposed system to test the network sensitivity using the Orbit Analysis and Simulation Software (OASIS) developed at the Jet Propulsion Laboratory (JPL) [3]. The analysis showed that GPS on-orbit accuracies of less than 50 cm are possible with FOGON using three stations in an orthogonal array separated by 40 to 60 km. An optical link calculation for the proposed system was also completed for a 40 km separation. It showed that the signal to noise (SNR) ratio of the link did not seriously degrade and that the input and output RF powers were acceptable for GPS receiver operation. The next logical step was to verify the results of the link calculation by performing a fiber optic hardware demonstration. This paper presents the results of an experiment carried out by members of the Colorado Center for Astrodynamics Research (CCAR) and the Optoelectronic Computing Systems Center (OCSC) at the University of Colorado (CU) which demonstrates that the analog transmission of GPS spread spectrum signals over a 4 km fiber optic links is possible with minimal degradation to GPS receiver operation. It is important to note that the equipment used in this experiment was originally designed for digital transmission and is not optimal for analog spread spectrum signals. However, the overall results are very encouraging.

GPS ANTENNA/RECEIVER OPERATION

In typical GPS receiver operations, the antenna and the receiver are usually separated by as much as 30 m of coaxial cable. Therefore, the antenna receives the incident RF power (GPS spread spectrum) which is then transmitted over the coaxial cable to the GPS receiver for data processing. The transmission over the coaxial cable can amount to as much as a 10 dB loss in signal power. The GPS spread spectrum signal consists of carriers that are phase modulated by two pseudo random noise (PRN) codes, a Coarse Acquisition (C/A) code and a Precision (P) code, which are generated at 1.023 MHz and 10.23 MHz chipping rates. The GPS receiver used in this demonstration was the ISTAC 2002 which derives the positional information based upon observations of Doppler and phase of the chipping frequency without knowledge of the pseudo random noise (PRN) codes used to generate the spread spectrum signals [4]. The receiver downconverts the GPS signal to a second intermediate frequency of 35.42 MHz. The receiver then multiplies the received signal by a delayed (of 1/2 the chip time of the PRN sequence) version of itself which collapses the

spread spectrum into a spectral line which contains the recovered chipping frequency of both the C/A and P channels that are exploited to derive the positional information.

In the proposed fiber optic system configuration, the antennas will be placed 40-80 km away from the receivers which means that the GPS spread spectrum signals must be transmitted 40-80 km over the fiber which will result in degradation of the SNR. The experimental procedure of this demonstration was to extract the IF spread spectrum signal from the receiver, optically transmit it down the fiber and then optically receive and demodulate the light signal, input the IF spread spectrum signal back into the receiver, and demonstrate that the receiver was still able to recover the chipping frequency as if the receiver had remained in its conventionally connected coaxial cable mode.

EXPERIMENTAL CONFIGURATION

A block diagram of the experimental configuration is shown in Figure 1. The spread spectrum signal (1575.42 $\pm$ 10 MHz) used in the experiment was generated by a (PRN) generator which emulated a GPS satellite signal. This signal was transmitted to the ISTAC 2002 GPS receiver by a small helical antenna. The signal source contained a carrier at 1575.42 MHz that was quadrature modulated by two PRN codes (P and C/A) to obtain the spread spectrum. The ISTAC receiver downconverted the spectrum to a second IF at 35.42 $\pm$ 10 MHz which had a power level of -27 dBm. Since this power level was not sufficient to modulate the LED, a + 30 dB gain stage was added to increase the power level to + 3 dBm. This 35.42 $\pm$ 10 MHz (+ 3 dBm) signal was added to a 100 mA bias current which then modulated the Light Emitting Diode (LED). The LED emits at 1300 nm with an output optical power of 16 μW when a 100 mA bias current is applied. The intensity modulated light then travelled down a 4.17 km spool of single mode fiber and was received by a photodiode detector. The photodiode detector then demodulated the light and output the 35.42 $\pm$ 10 MHz spread spectrum signal which sustained an SNR degradation and RF power loss of approximately 2 dB. To determine whether the fiber optic link successfully transmitted the spread spectrum signal, the 35.42 $\pm$ 10 MHz signal was returned to the 2nd IF input of the GPS receiver where the chipping frequency was recovered. To establish a reference level of the required SNR and RF power levels of the recovered chipping frequency, the GPS receiver was also run in a normal mode of operation using a 5 cm length coaxial cable connection without the fiber optic link (as shown by the dashed line in figure 1). Two spectrum analyzers were used: 1) an HP 3582A to measure the recovered chipping frequency down-converted to approximately 292 Hz and 2) a Tektronix 1701 to

observe the 35.42 $\pm$ 10 MHz spread spectrum signal. A photographic record was made of the spectrum analyzer output. An equipment list for the demonstration is shown in Figure 2.

RESULTS

The GPS receiver was first run in a normal mode of operation without the fiber optic link. Figure 3 shows the I.F. power spectrum after the + 30 dB gain stage (at point A in Figure 1) and with the PRN generator off. This condition established a measure of the amplifier noise power and bandwidth characteristics. Figure 4 shows the spectrum at the same point with the PRN generator turned on. Note that the signal is not much different than the amplifier noise power. This signal was then input to the GPS receiver without the +30 dB gain stage where the receiver recovered the chipping frequency as shown in Figure 5. The recovered chipping frequency signal at 292 Hz had a 506 mV level and a numerical voltage SNR of 500 in the normal mode of operation.

The same series of measurements was then taken with the fiber optic link inserted in the system. Figure 6 shows the IF spectrum at the output of the photodiode detector with no PRN signal input to the amplifier which is similar to the case shown in Figure 3. The PRN generator was then turned on and the result is shown in Figure 7. Comparing this with Figure 4 shows no noticable degradation due to the fiber optic link. The signal was then returned to the GPS receiver which recovered the chipping frequency as shown in Figure 8. The recovered chipping frequency of 292 Hz had a voltage level of 10.8 mV. The voltage level of the system when the fiber optic link was used was less than the normal receiver operation, but the signals were easily large enough for the ISTAC GPS receiver to maintain it's operation.

CONCLUSIONS

The possibility of exploiting relatively closely spaced tracking sites connected by fiber optics to enable the use of a common time and frequency source for multiple GPS receivers, offers an interesting possibility for significant improvements in GPS orbit accuracy and reliability. The hardware demonstration presented in this paper illustrates that GPS spread spectrum signals can be successfully transmitted from a GPS receiver intermediate frequency stage over 4.2 km of fiber optic cable to a signal processor and then

despread to extract the positional information. The experimental configuration used in this demonstration can be improved upon to optimize it for analog modes. The next phase of the experiment will involve transmissions over a longer link (~ 40 km) with customized electronics and a laser diode to further demonstrate the validity of the technique.

REFERENCES

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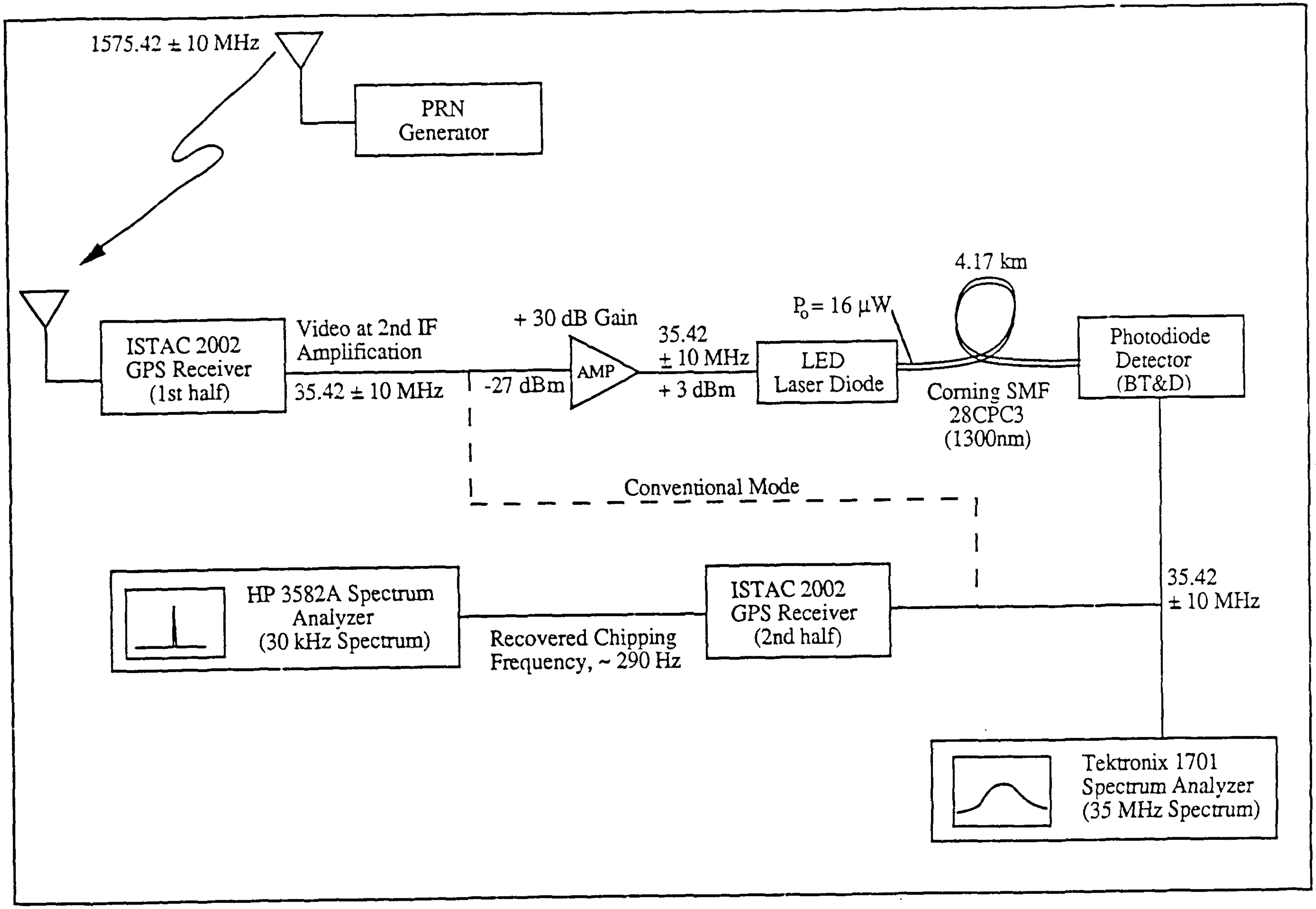


Figure 1. Experimental Configuration of the GPS Fiber Optics Demonstration

Feb. 90

Figure 2. Fiber Optics Demonstration Equipment List

1. 1 1.3 μm LED, Laser Diode model LDT60005E
2. 1 Photodiode Detector, British Telecom & Dupont
3. 4.17 km 1.3μm single mode spool of fiber, Corning SMF 28CPC3 (Corning is thanked for supplying the fiber)
4. 1 ISTAC 2002 GPS codeless receiver
5. 1 PRN Generator
6. 1 HP 3582A Spectrum Analyzer (30 kHz spectrum)
7. 1 Textronix 1701 Spectrum Analyzer (35 MHz spectrum)
8. 1 + 30 dB op-amp, Comlinear Corporation model CLC401
9. 1 HP triplet power supply
10. 3 single power supplies
11. Index matching fluid
12. 3 BNC banana plug cables
13. 2 SMA cables
14. 2 SMA to BNC converters
15. 1 100 Ω resistor, 1 100 mH inductor, 1 .1 μF capacitor
16. 1 camera
17. 1 helical antenna

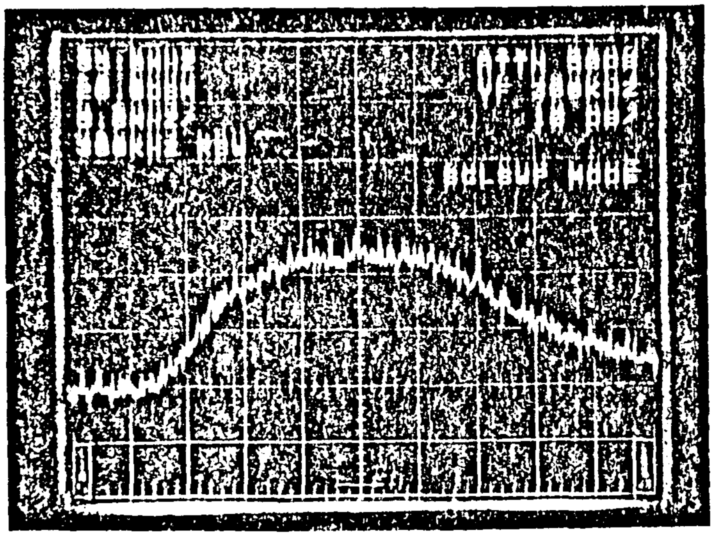


Figure 3.

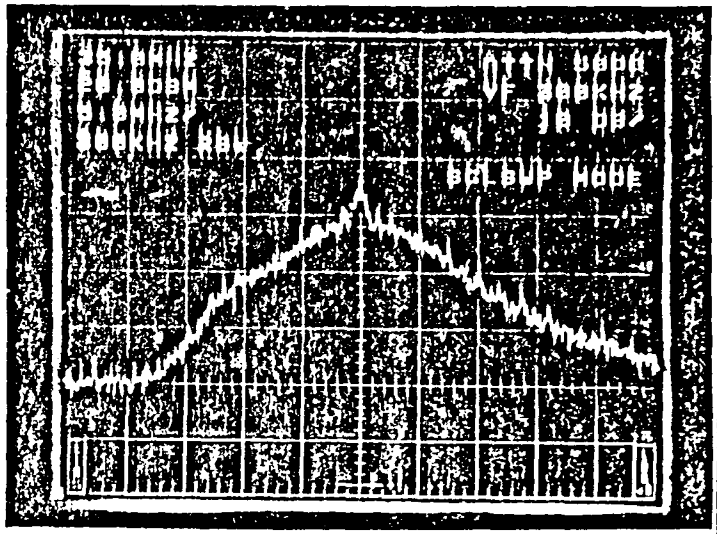


Figure 4.

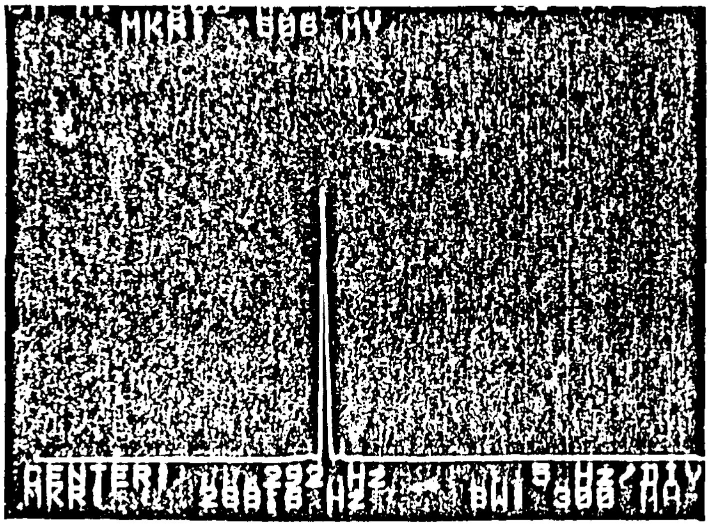
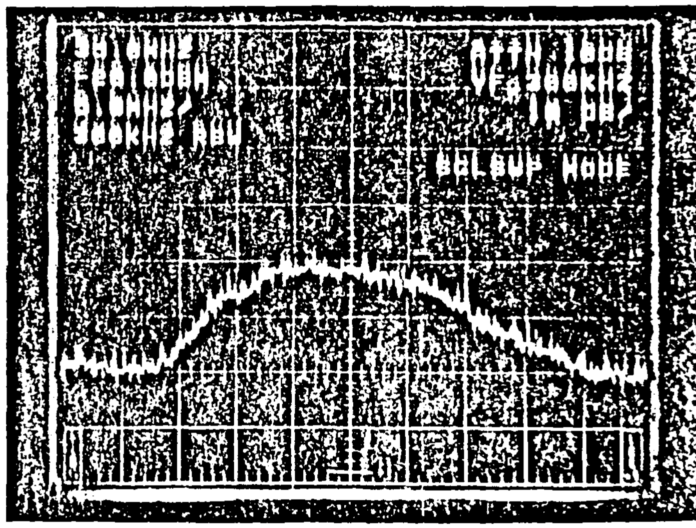


Figure 5.



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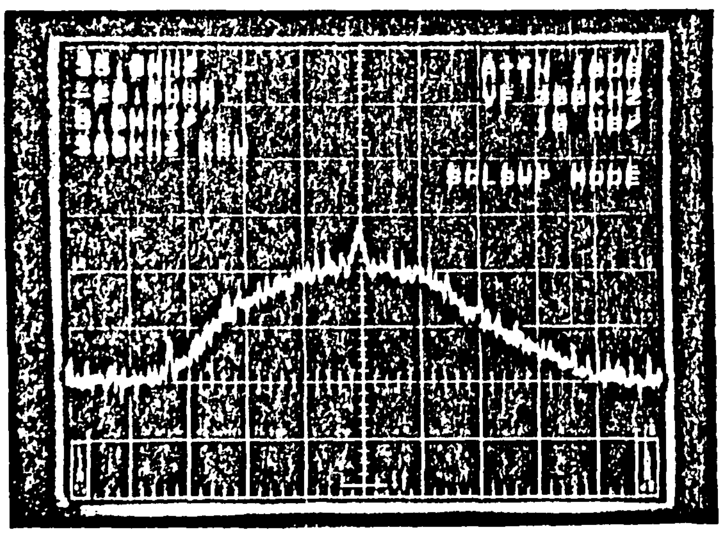

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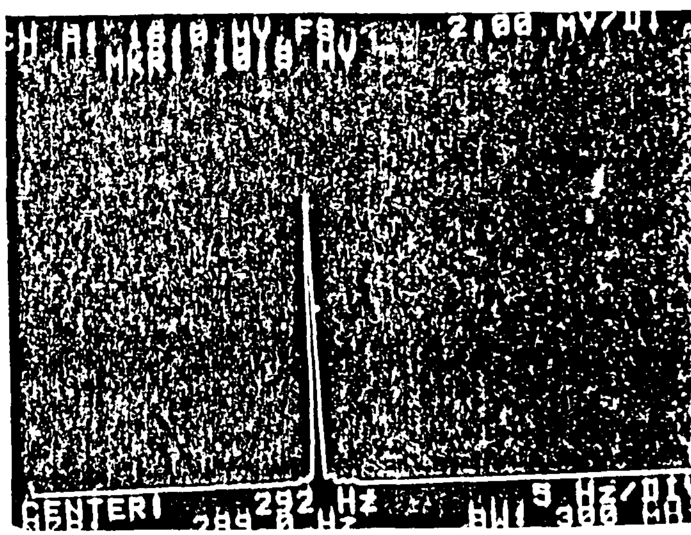

Figure 8.